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HIGH VOLTAGE PLASMA SHEATH ANALYSIS
RELATED TO TSS-1

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Introduction

On the first mission of the Tethered Satellite System (TSS-1), a 1.8m diameter spherical satellite will be deployed a distance of 20 km above the space shuttle Orbiter on an isulated conducting tether. The satellite will be held at electric potentials up to 5000 volts positive with respect to the ambient plasma. Due to the passage of the conducting tether through the earth's magnetic field, an emf will be created, driving electrons down the tether to the orbiter, out through an electron gun into the ionosphere and back into the positive-biased satellite. Instrumentation on the satellite will measure electron flow to the surface at several locations, but these detectors have a limited range of acceptance angle. The problem addressed herein is the determination of the electron current distribution over the satellite surface and the angle of incidence of the incoming electrons relative to the surface normal.

The Mathematical Model

In the ionosphere at the altitude of the planned orbit, the average thermal velocity of electrons 1.9×10^5 m/s, the average thermal velocity of the ions is 1.1×10^3 m/s and the velocity of the satellite is 8×10^3 m/s. Furthermore, the electrons spiral about the earth's magnetic field lines (0.4 Gauss) with a radius of 3 cm, while the ions spiral with a radius of 5m. Under these conditions, the electron thermal energy, $kT = 0.17$ eV and the satellite radius $R_p = 163$ Debye lengths.

In the present calculation, it is assumed that there will be a sheath region around the satellite devold of ions due to the high positive potential and that electrons approach this sheath along the magnetic field lines neglecting their initial velocity due to the ambient spirals. The governing equations in this sheath are taken to be (1) the Steady-state Taylor-Vlasov equations which relate the components of the electron velocity to the local electric potential, (2) the continuity equation for electrons which relates their velocity components to the electron density and, (3) the Poisson equation which relates the electron density to the electric potential. The boundary conditions at the outer edge of the sheath are that the electron velocity is equal to the ambient electron drift velocity, the electron density is the ambient value.

Symmetry conditions which apply at the magnetic pole and equator are used in equations (1)-(3) to obtain a single ordinary differential equation. This equation is solved in each region by backward differencing and the potential distributions and location of the space charge minima for the pole and equator are determined. The angular weighted average of these solutions at the radius of the equatorial space charge minimum is used as the outer boundry condition for the potential.

The Solution

Finite difference equations, using backward differencing for equations (1)-(2) are solved simultaneously. Equation (3) is solved by the successive over-relaxation method. The computer program begins by using a guessed potential distribution and solving equations (1)-(2) to obtain the electron density. Using this

electron density a new potential distribution is obtained and used in equations (1)-(2), repeating the cycle. The above process is repeated until potential, electron density, and electron velocity spacial distributions have converged. Then the angles of incidence of the current to the satellite surface are obtained from the electron velocity components.

Results

The computational program has been carried out for satellite potentials from 100 to 100,000 (in units of kT). The sheath radius R_s at the magnetic equator (the lcoation of the space charge minimum) is compared to the satellite radius R_p in the table below.

Sheath Radius

Satellite potential, Vp (kT)	Rs/Rp
100	1.125
1,000	1.566
10,000	2.922
30,000	4.131
100,000	6.418

The sum of the radial and polar velocity vector components are shown in Figure 1 and a contour plot of the magnitude of the corresponding azimuthal velocity components is presented in Figure 2. As the satellite potential is increased from 100 to 100,000 kT this azimuthal velocity component increased especially in the equatorial region. Above 30,000 kT electrons no longer make contact with the surface at the equator.
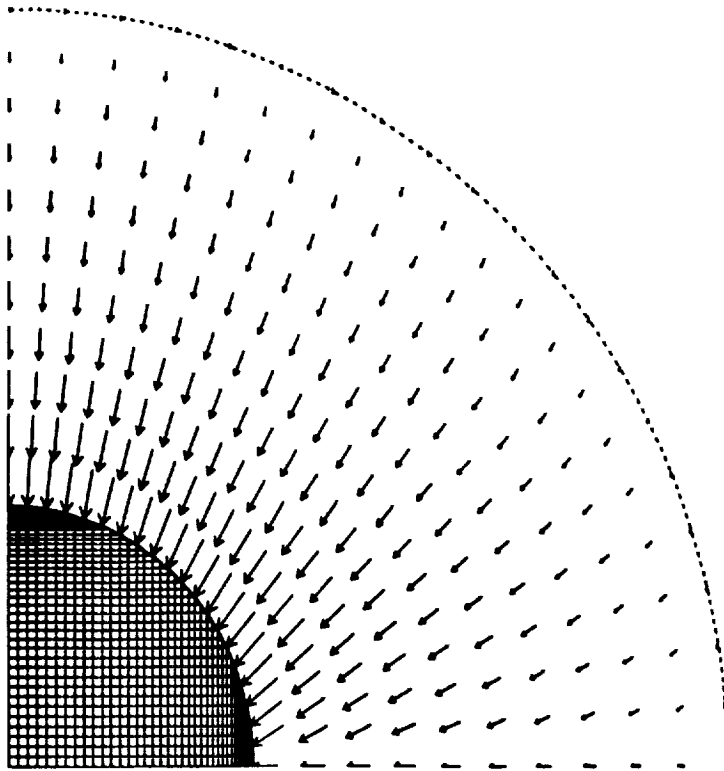
Acknowledgment

Figure 1. Electron velocity vectors (radial + polar components). V_p = 10,000
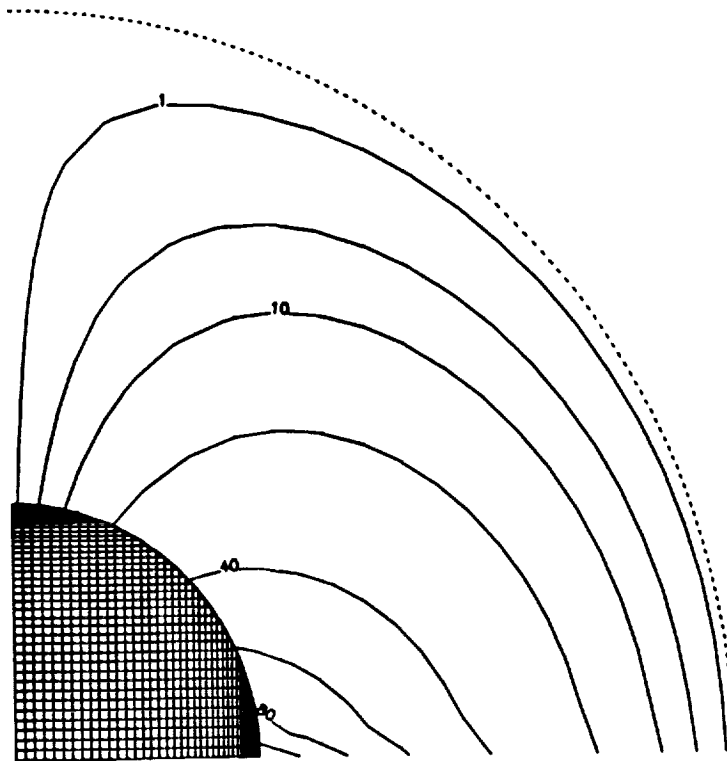

Figure 2. Magnitude of the electron Azimuthal velocity component (in units of ambient electron thermal velocity). Vp = 10,000